INVESTIGATION OF SULFIDE STRESS CORROSION CRACKING IN LOW ALLOY STEELS

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The complex program of physical-chemical and mechanical investigations on sulfide stress corrosion cracking in low alloy steels is executed. The time to crack initiation, the behaviour of crack growth and K_{1ssc} value on DCB-specimens is determined. The influence of nonmetallic inclusions on fracture mechanism's nature is estimated. Taking into account the microstructural character of hydrogen embrittlement the kinetic model of damage accumulation is proposed.

INTRODUCTION

Sulfide stress corrosion cracking (SSCC) of oil country tubular goods is still one of the most important problems in sour oil and gas wells. SSCC is a complex process of interaction between H_2S environment and metals. This process may be devided into three stages - incubation stage, stage of subcritical corrosion crack growth and stage of dynamic crack propagation. For reliable time to failure prediction and current control of metall quality it's necessary to determine SSCC duration, physical mechanism of damage accumulation (initiation, growth and coalescence of microcracks), damage correlation with K_{1ssc} and K_{1c} values.

In the present work SSCC in low alloy steels was studied. On DCB-specimens the behaviour of crack growth and K_{1ssc} value was determined. The role of nonmetallic inclusions was analised.

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EXPERIMENTAL PROCEDURE

Materials. The steels of oil pipes used in this investigation are marked by 30G2 (C=0.32, Mn=0.97, Si=0.25, P=0.035, S=0.031 wt %) and C-75-2 (C=0.26, Mn=0.99, Si=0.24, P=0.027, S=0.024 wt %). The 30G2 steel was normalized from rolling temperature and had a ferrite-perlite microstructure (graine size 20-30 µm) with a large number of elongated sulfides (Fe, Mn)S measuring 800-15-5 µm. The C-75-2 steel was quenched and tempered to a martensite microstructure with austenite grain size of 30-40 µm and nonmetallic spheroidized sulfides or oxisulfides inclusions by 5-7 µm in diameter.

The room temperature tensile properties of investigated steels are given in Table 1.

Specimens. The sulfide stress cracking resistance of metalls was determined with double cantilever beam (DCB) specimens wich were cut longitually from 10 mm thickness oil pipes. The 25 mm height, 8 mm width and 100 mm length wedge-loaded DCB specimen has 34 mm length initial notch with 0.1 mm root radius and two 45° side groovers reduced the width of specimen to 4.8 mm.

Testing procedure. The testing procedure for K_{1SSC} determination on DCB-specimens has been described in detail by Heady (1). Briefly, the specimens are loaded by means of wedge and placed in NACE solution (5% NaCl+0.5% CH_3COOH, H_2S=2500 mg/l, pH=3.4). After removal from the test solution the one part of specimens are fractured and sulfide stress crack length is measured. The next part of specimens are polished and used for analysis of crack trajectory and near the crack tip damage observation.

TABLE 1 - Room temperature mechanical properties of low alloy steels.

Steel	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	Reduction of area (%)
30G2	655	380	16	50
C-75-2	681	589	24	71

K_{1ssc} calculation. To calculate the K_{1ssc} value on the expression of Heady (1)

$$K_{1ssc} = Pa(2\sqrt{3} + 2.38\frac{h}{a})(\frac{B}{B_0})^{1/\sqrt{3}} /Bh^{3/2} \ldots\ldots\ldots (1)$$

it's necessary to know the equilibrium crack length a and equilibrium wedge load P. The direct measurement of P is not accurate and (1) should be replaced by the expression with total opening specimens arms

$$K_{1ssc} = A(1 + ch/a)/(1 + 3ch/a + 3(ch/a)^2) \ldots\ldots (2)$$

where $c = 2.38/2\sqrt{3}$, $A = \sqrt{3}E\Delta h^{3/2}(B_0/B)^{1/\sqrt{3}-1}/4a^2$.

Using (2) for initial and equilibrium crack length with constant Δ this expression may be written as

$$\frac{K_{1ssc}}{K_{10}} = \frac{(1+ch/a)(1+3ch/a_0+3(ch/a_0)^2)}{(1+ch/a_0)(1+3ch/a+3(ch/a)^2)}(\frac{a_0}{a})^2 \ldots\ldots (3)$$

The K_{10} value for initial wedge load P_0 and initial crack length a_0 is determineted using expression (1).

RESULT AND DISCUSSION

SSC-resistance testing. For investigation of SSCC on DCB-specimens two levels P_0=2 KN and P_0=4 KN of initial wedge load was choosen. The initial values of K_{10} for this load levels are K_{10}=35 MPa$\sqrt{m}$ and K_{10}=70 MPa$\sqrt{m}$. The specimens are left in the test solution for 8, 24, 180 and 360 hours. The crack length increments Δa for this test time and K_{1ssc} values in Table 2 are placed.

This results has shown that for 30G2 steel $K_{1ssc} \sim$ 33 MPa$\sqrt{m}$ and for C-75-2 steel K_{1ssc}=(19-22) MPa$\sqrt{m}$. The great value of K_{1ssc} for 30G2 with P_0=4 KN means that ASTM's criterion for plain strain condirions

$$B_0 > 2.5(K_{1ssc}/\sigma_Y)^2 \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

is not valid and near the crack tip there exist a great plastic zone.

TABLE 2 - The results of sulfide corrosion crack growth tests and K1ssc values.

	30G2 steel		C-75-2 steel	
Time (h)	P=2 KN Δa (mm)	P=4 KN Δa (mm)	P=2 KN Δa (mm)	P=4 KN Δa (mm)
8	0.0	1.0	0.0	4.0
24	0.5	2.5	0.0	14.0
180	1.0	4.0	15.0	26.0
360	1.0	4.0	15.0	32.0
K_{1ssc} (MPa$\sqrt{m}$)	33	58	19	22

Microstructural analysis. The fracture surface and crack trajectory in DCB-specimens has been examined using metallographic techniques.

Figure 1 is a photomicrograph of polished and etched DCB-specimen from 30G2 steel. It's seen that near the crack tip a secondary cracks are placed. The scanning electron micrographs of fractured surface has shown the embrittled zone around of elongated sulfides. The crack grow by jumping - on the Figure 2 position of main crack with a secondary cracks for three time (8, 24 and 360 hours) are presented. This mechanism of crack growth is connected with degradation of mechanical properties near the crack tip and can be described by theoretical model of Astafjev and Loginov (2). On the Figure 3 the change of Knoopp hardness ΔH near the crack tip is plotted.

Figure 4 are a photomicrograph of polished and etched DCB-specimen from C-75-2 steel and scanning electron micrographs of the fractured surface. It's seen that C-75-2 steel has a mixed transgranular and intergranular brittle fracture mode. Near the crack tip there exist a great number of microcracks placed on austenite grain boundaries.

CONCLUSION

The results of this investigation clearly demonstrate the difference in SSCC resistance of 30G2 and C-75-2 steels.

In 30G2 steel the main feature of fracture are the high value of K_{1ssc}, initiation of a secondary cracks on sulfides and coalescence of this cracks with the main crack tip.

The C-75-2 steel has a mixed transgranular and intergranular brittle fracture mode with great number of austenite grain sized microcracks ahead of a crack tip and a small value of K_{1ssc}.

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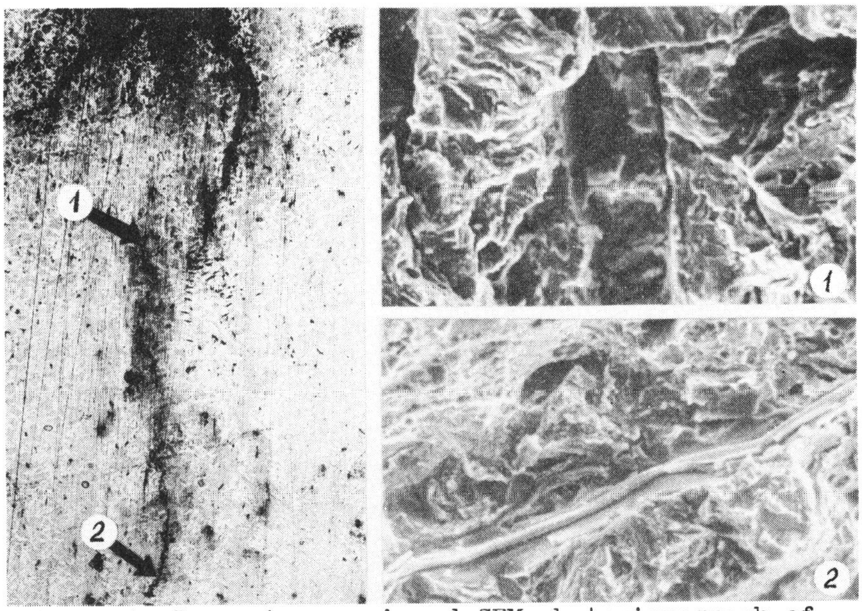

Figure 1. Corrosion crack and SEM photomicrograph of fractured surface in 30G2 steel.

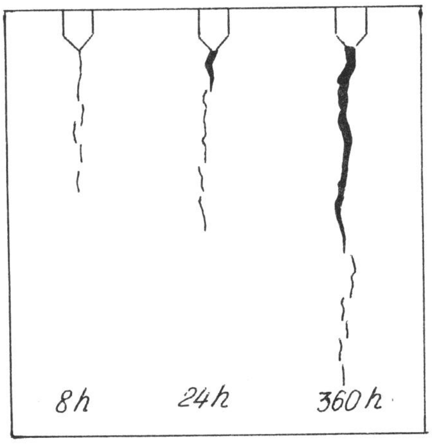

Figure 2. The process of crack growth in 30G2 steel

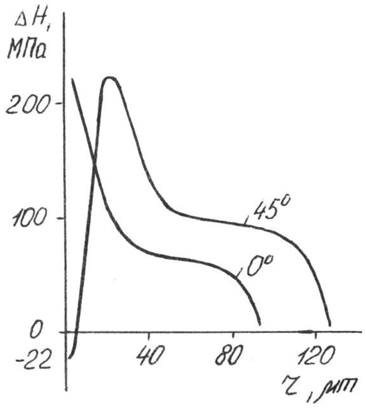

Figure 3. The hardness distribution near a crack tip

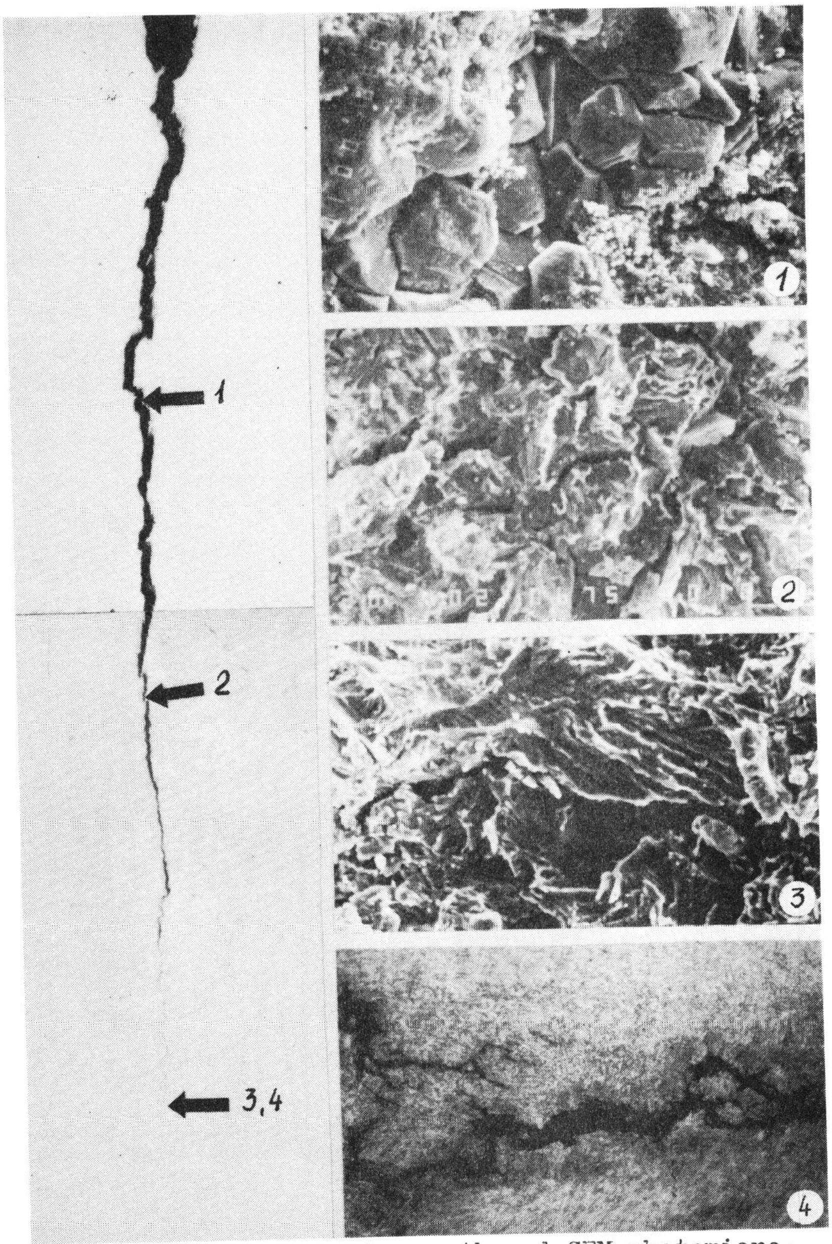

Figure 4. Corrosion crack growth and SEM photomicrographs of fractured surface in C-75-2 steel.